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Refraction gratings

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With 2 figures in the text

If a diffraction grating is operated in a transparent medium of high refractive index the process of diffraction will change essentially. This can be demonstrated either by ruling a grating on the 'back' surface of a plane-parallel plate of glass or by bringing the plate into optical contact with a plane grating by some appropriate immersion liquid[1].

Applying the general grating formula to the case of autocollimation, we introduce the following equations, holding for a parallel beam of light passing through the glass plate and the immersion-film with refractive indices μ_β and μ_α respectively, and diffracted at the grating according to figure 1:

$$\begin{aligned} \mu_\alpha \sin\alpha = \mu_\beta \sin\beta = \sin\gamma, \\ m\lambda = 2\,\mu\,\sigma \sin\alpha\,. \end{aligned} \tag{1}$$

Here, α is the angle of incidence at the grating, β and γ are the angles of refraction in the glass plate and in the air ($\mu = 1$), σ is the grating constant and λ is the wavelength in the air. The diffraction at this compound grating therefore obeys the equation

$$m\lambda = 2\,\sigma \sin\gamma, \tag{2}$$

corresponding to an increase of the angle of incidence α at the surface to the angle γ, as indicated by the dotted line in figure 1.

The advantages of the compound grating are obvious. Neglecting the absorption and the reflection in the glass plate and the immersion-film one expects to find a close agreement between the intensity distribution in different orders m of an ordinary grating and the corresponding orders $\mu_\alpha m$ of the compound grating. Thus a grating favoured by 'blaze' in an order m will have this blaze shifted into the higher order $\mu_\alpha m$ when it is used as a compound grating. Appropriately we may here also introduce the name refraction grating.

The properties of the refraction grating can be checked in accordance to figure 1. If we bring the glass plate into optical contact with the upper or the

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[1] The idea of bringing a glass plate into optical contact with a diffraction grating was advanced long ago by R. W. Wood, although he intended a totally different application than that here considered. R. W. Wood, Phil. Mag. *4*, 396, 1902.

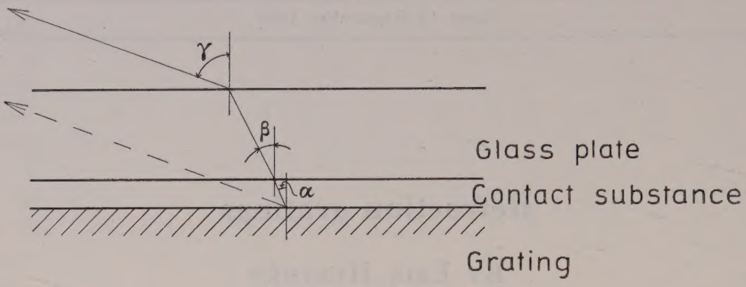

Fig. 1.

lower section of a plane grating, we may observe visually two kinds of spectra: one produced by the uncovered grating as indicated by the dotted line in figure 1, and another produced by the refraction grating. These two spectra will coincide in all orders in accordance to equation 2. Consequently the principle of coincidence holds for the refraction grating as well as for the ordinary grating.

An examination of the effect of different immersion liquids such as glycerine, castor and cedar oils, turpentines etc. showed a striking shift in intensity from the second and the third orders to the fourth order in the spectrum. This effect was observed with a 3-inch plane grating ruled on Rowland's machine in 1889 (14 400 lines/inch). Judging from the times of exposure of the green mercury line λ 5 461 in the fourth order of the spectrum, this intensification is very high, more than a factor of ten. It was, however, also found that the choice of the immersion liquids sensibly affects the image definition of the spectral line, some immersions, such as the turpentines, being more favourable than others, e. g. glycerine. Probably this blurring of the spectral line arises from 'Schlieren' phenomena produced by density fluctuations or lack of homogeneity in the immersion-film. The necessity for a high degree of optical homogeneity in the medium in front of the grating was demonstrated in the following way. A resistance wire mounted close below the front of a 21' concave grating was heated imperceptibly by an electric current. When a spectral line was observed through a magnifier, the blurring was seen to appear and disappear shortly after the switching on and the breaking of the current.

This blurring effect from the immersion-film between the grating and the glass plate probably implies a severe hindrance to the attainment of a high spectroscopic resolution. It was, therefore, already at an early stage of the investigation, decided to eliminate the film by ruling the grating directly on the 'back' surface of an optically homogeneous glass plate, afterwards aluminizing the ruled surface by evaporization. To avoid secondary spectra produced by internal reflections in the plate, the latter is designed as a circular and slightly wedge-shaped disk, whereupon the grooves are ruled perpendicular to the wedge line. The primary and the secondary spectra[1] will thus appear separately, one below the other. It is also useful to mount the grating on a revolving axis, so that it can be operated from both sides as an ordinary diffraction grating as well as a refraction grating. Through the courtesy of Pro-

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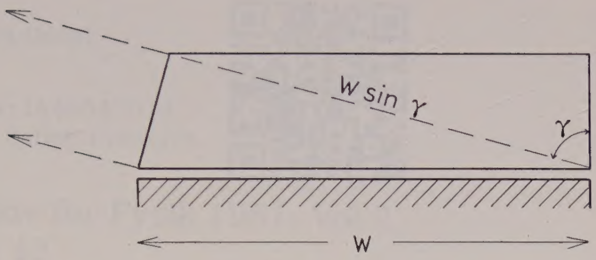
[1] E. Hulthén and E. Lind, Arkiv för Fysik, *2*, 253, 1950.



Fig, 2.

fessor M. Siegbahn, the ruling operation is now performed with the ruling machine of the Nobel institute for Physics at Frescati, Stockholm. The circular glass disk, 150 mm in diameter and of 10 mm's thickness, was manufactured at the AGA Optical Department, Lidingö. The slight thickness of the disk was designed to reduce the optical path of the beam inside the glass, at the same time as care was taken not to risk deformation when mounting the grating.

In the ordinary dense-ruled diffraction grating ($\sigma \approx 2 \cdot 10^4$ Å) the blaze generally appears in the first or in the second order of the spectrum corresponding to diffraction angles $\alpha < 40^\circ$. The diffracted rays are therefore transmitted by the glass plate without great losses of reflection. In the coarse-ruled echelle gratings ($\sigma \approx 10^6$ Å), recently introduced by Harrison[1], the blaze appears, however, at nearly grazing angles of diffraction. Applying the principle of the refraction grating to this case and to avoid total reflection it will be advantageous to let the beam pass normally through a side facet in the glass plate, as indicated in figure 2. This arrangement, however, needs a glass plate of very high optical qualities as compared with that required for the arrangement in figure 1. The relations of the prismatic refraction grating will be discussed in a coming paper.

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[1] G. R. Harrison, J. Opt. Soc. Am. *40*, 127, 1950.

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